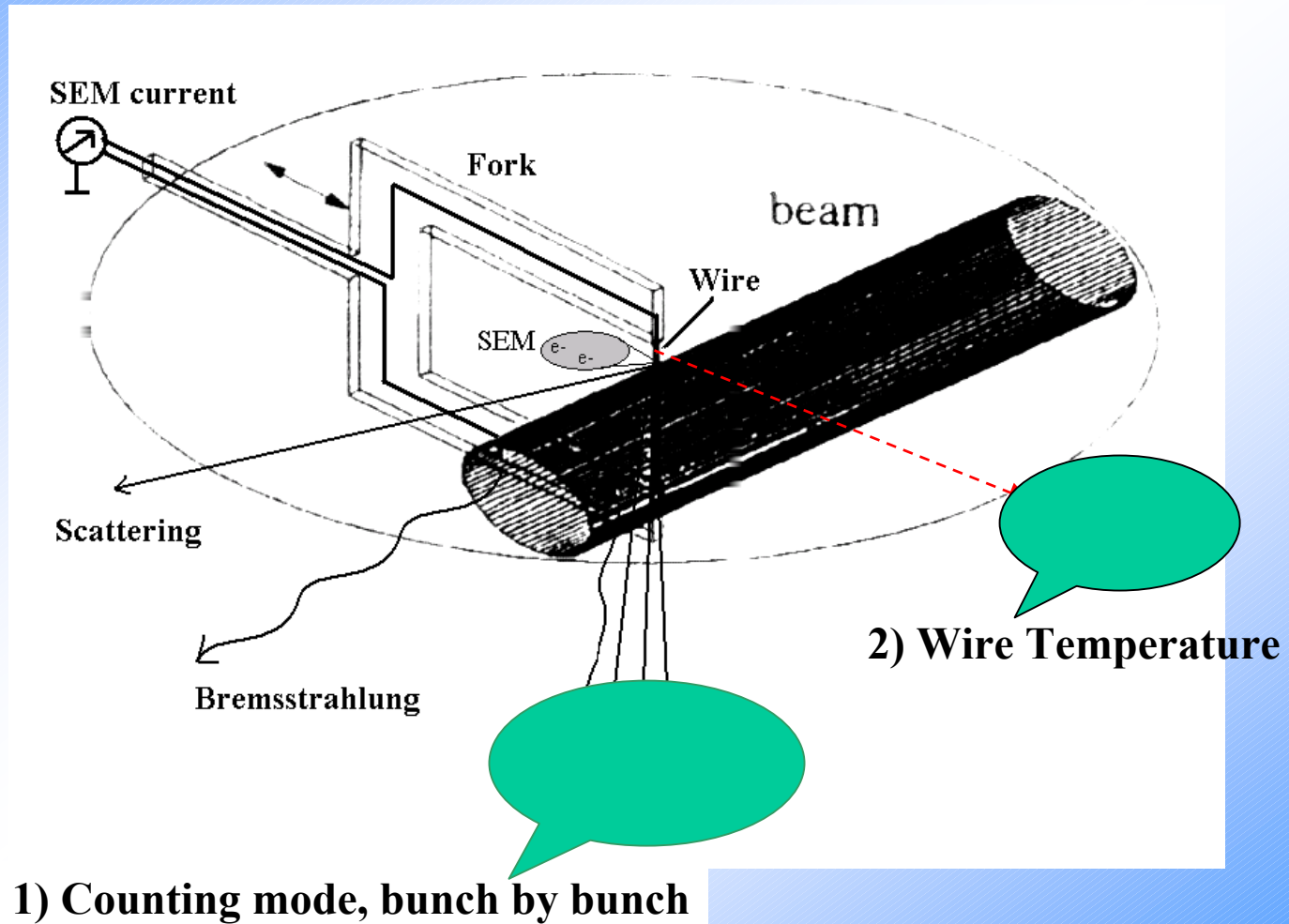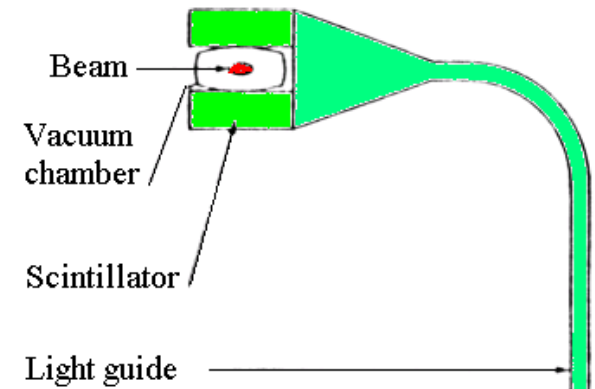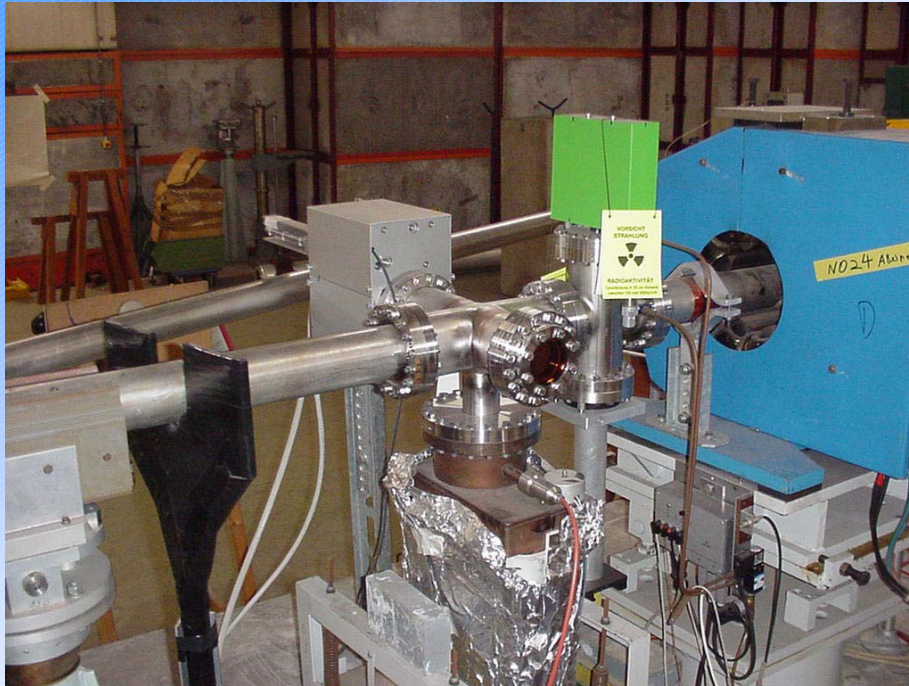# Beam tail measurements by wire scanners
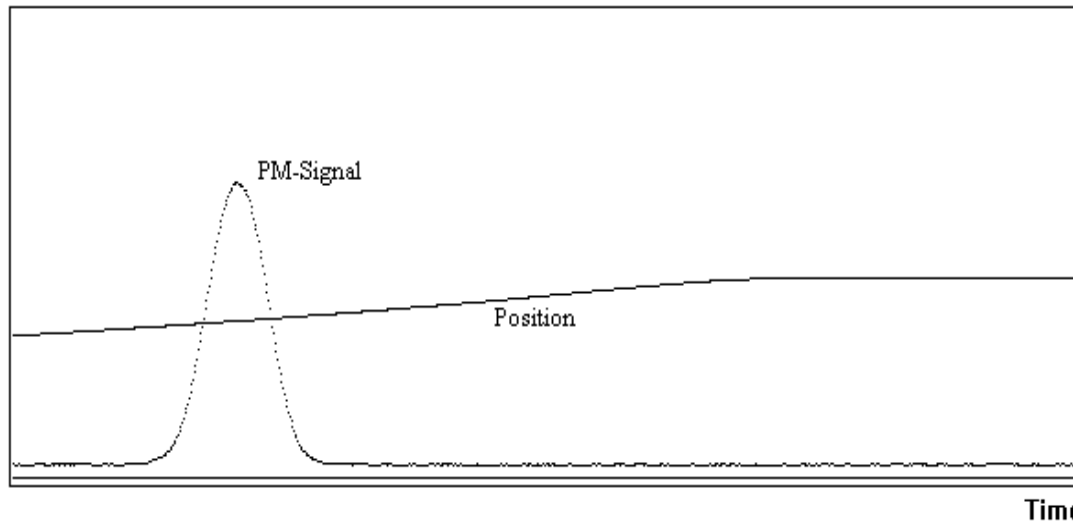
By Kay Wittenburg,
Deutsches Elektronen Synchrotron DESY, Hamburg, Germany



**1) Counting mode, bunch by bunch**

**2) Wire Temperature**

# Typical Wire Scanner Setup



Beam

Vacuum chamber

Scintillator

Light guide

Detector box

Photomultiplier

Volt

PM-Signal

Position

Time
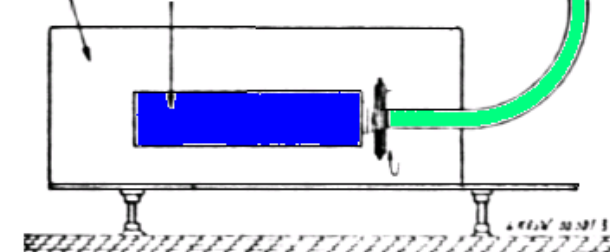
# 1) Counting Mode
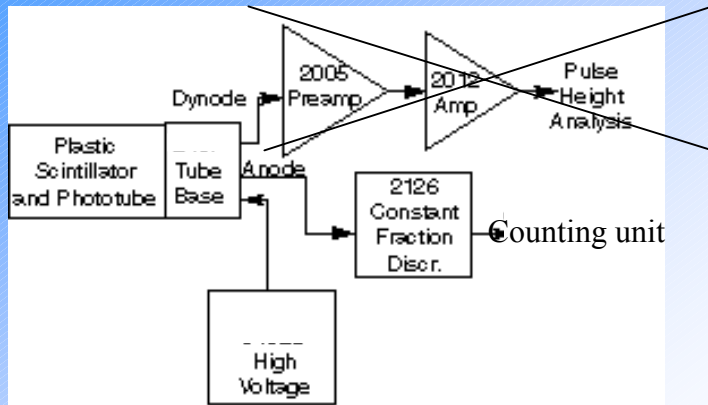


Figure 1.8: Plastic Scintillation Detector Electronics



count

Discriminator Level

No count

Rate: [Counts/bunch] [Counts/s]
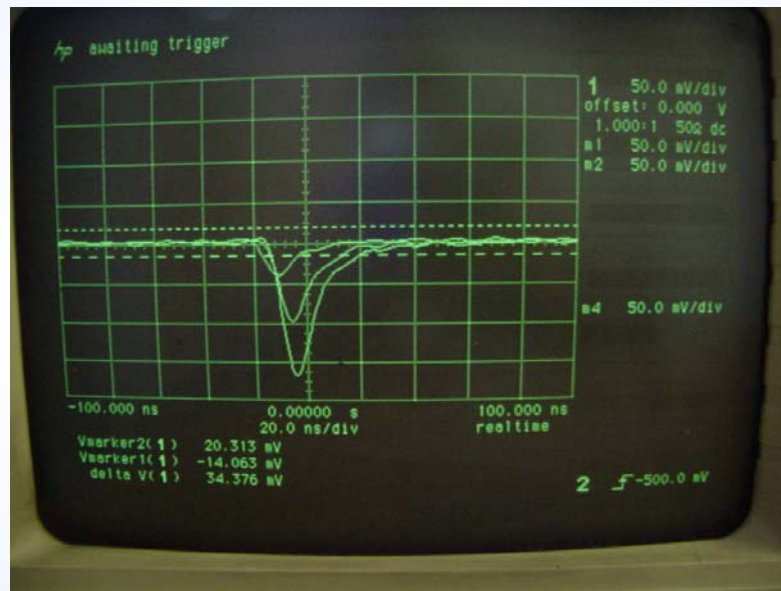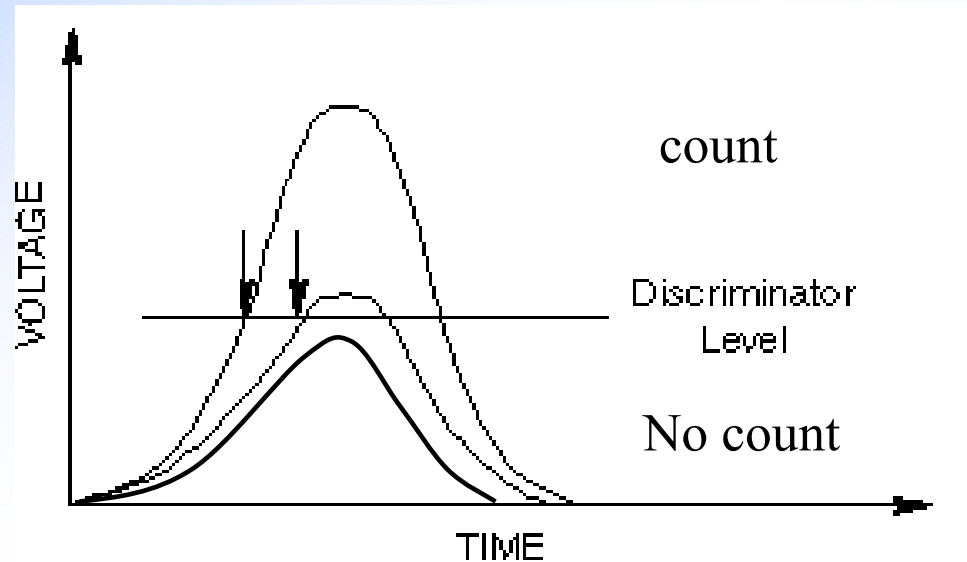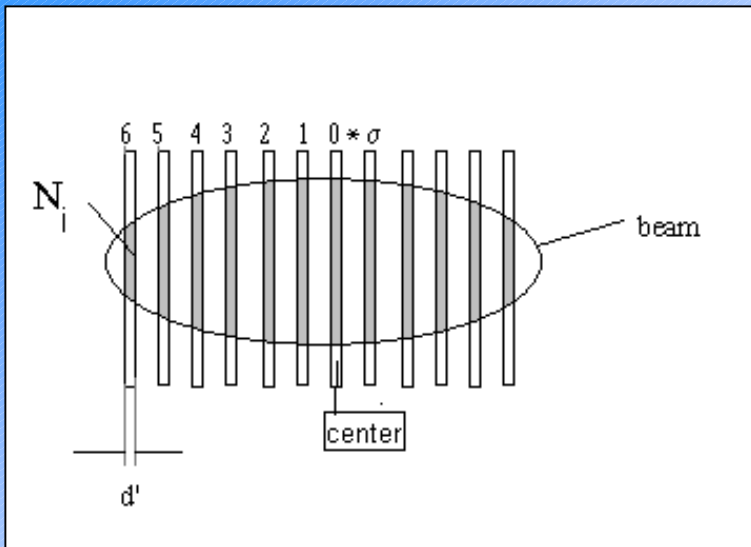
$$N_i = n_{bunch} \cdot \int_{i\cdot\sigma-\frac{d'}{2}}^{i\cdot\sigma+\frac{d'}{2}} \frac{1}{\sigma_h \cdot \sqrt{2\cdot\pi}} \cdot \exp\left(\frac{-x^2}{2\cdot\sigma_h{}^2}\right) dx$$

| Position | $N_i =$ | $Eff_i =$ | $S_i =$ |
|----------|---------|-----------|---------|
| Center | $1.484\cdot10^8$ | 14.837 | $1.543\cdot10^8$ |
| 1 σ | $8.999\cdot10^7$ | 8.999 | $9.359\cdot10^7$ |
| 2 σ | $2.008\cdot10^7$ | 2.008 | $2.088\cdot10^7$ |
| … | $1.648\cdot10^6$ | 0.165 | $1.714\cdot10^6$ |
| | $4.978\cdot10^4$ | $4.978\cdot10^{-3}$ | $5.177\cdot10^4$ |
| | 553.033 | $5.53\cdot10^{-5}$ | 575.154 |
| 6 σ | 2.26 | $2.26\cdot10^{-7}$ | 2.351 |
| | $3.399\cdot10^{-3}$ | $3.399\cdot10^{-10}$ | $3.534\cdot10^{-3}$ |
| | $1.88\cdot10^{-6}$ | $1.88\cdot10^{-13}$ | $1.955\cdot10^{-6}$ |
| | $3.825\cdot10^{-10}$ | 0 | $3.978\cdot10^{-10}$ |
| | $2.864\cdot10^{-14}$ | 0 | $2.978\cdot10^{-14}$ |

Saturation

Lower limit

N = **protons intersecting wire area**
σ = beam width (0.527 mm)
d' = wire diameter (7 μm)
$N_{bunch} = 2.8 * 10^{10}$ protons
Bunch Rate = 1/96 ns = 10.4 MHz
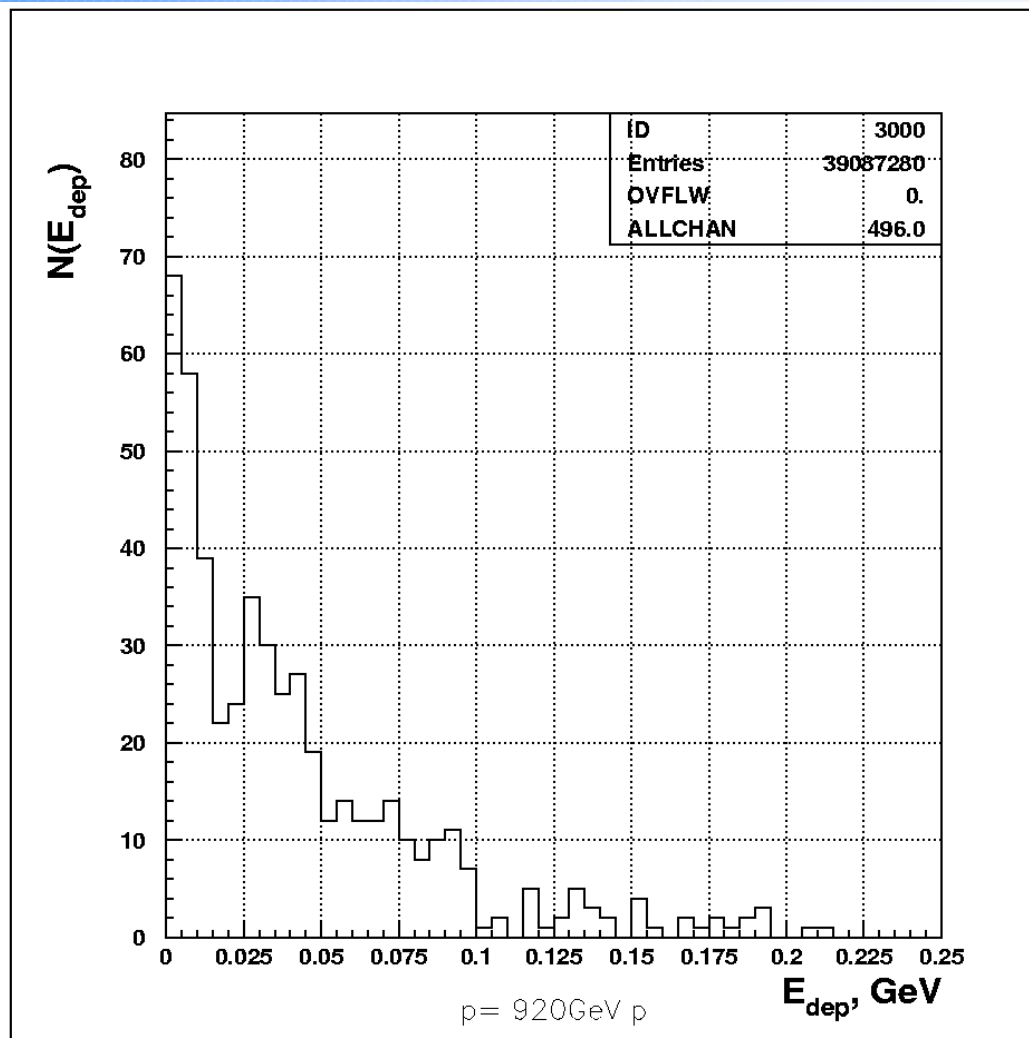
Assume signal efficiency of $10^{-7}$

# Monte Carlo Simulation (920 GeV/c protons)



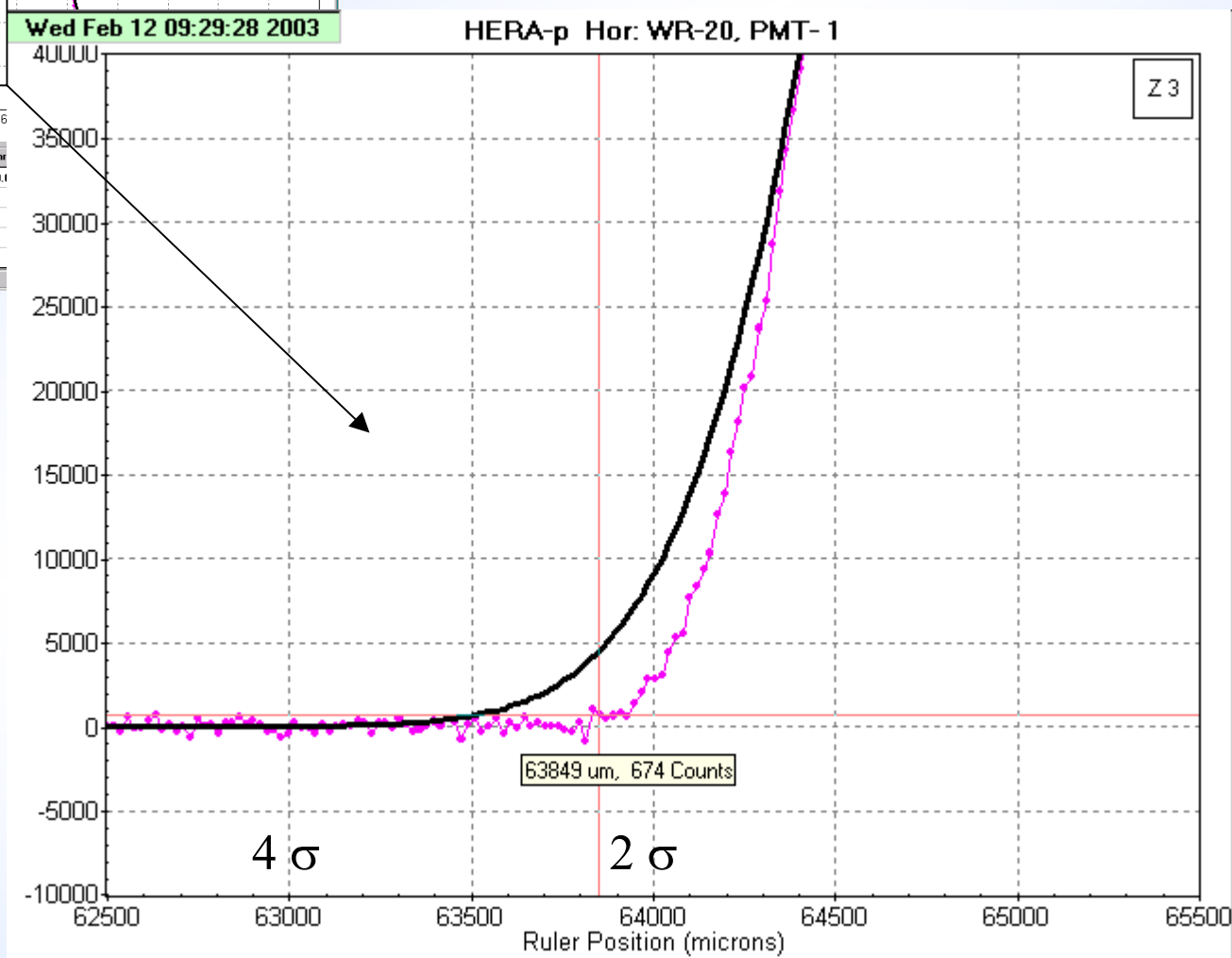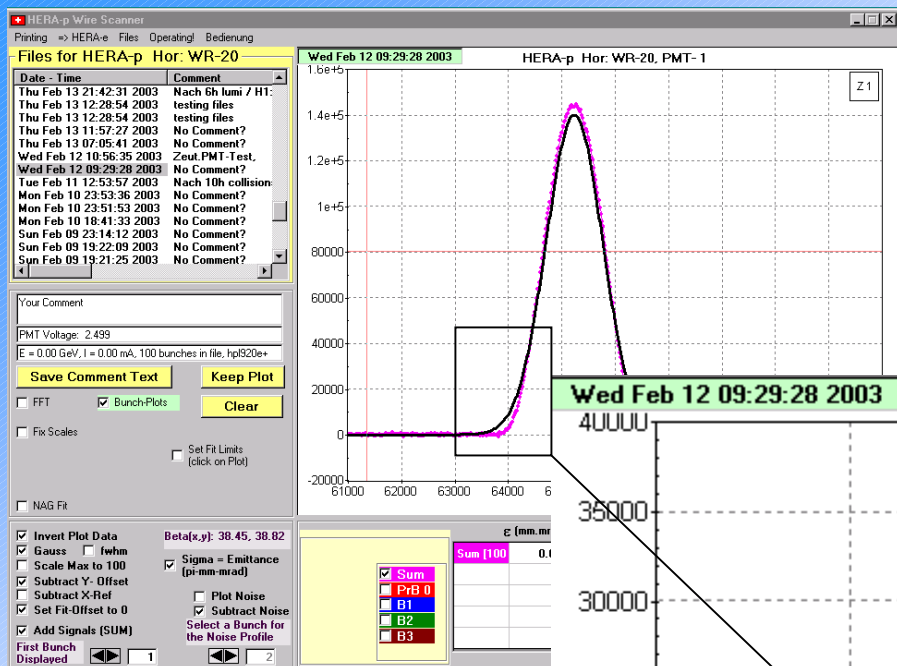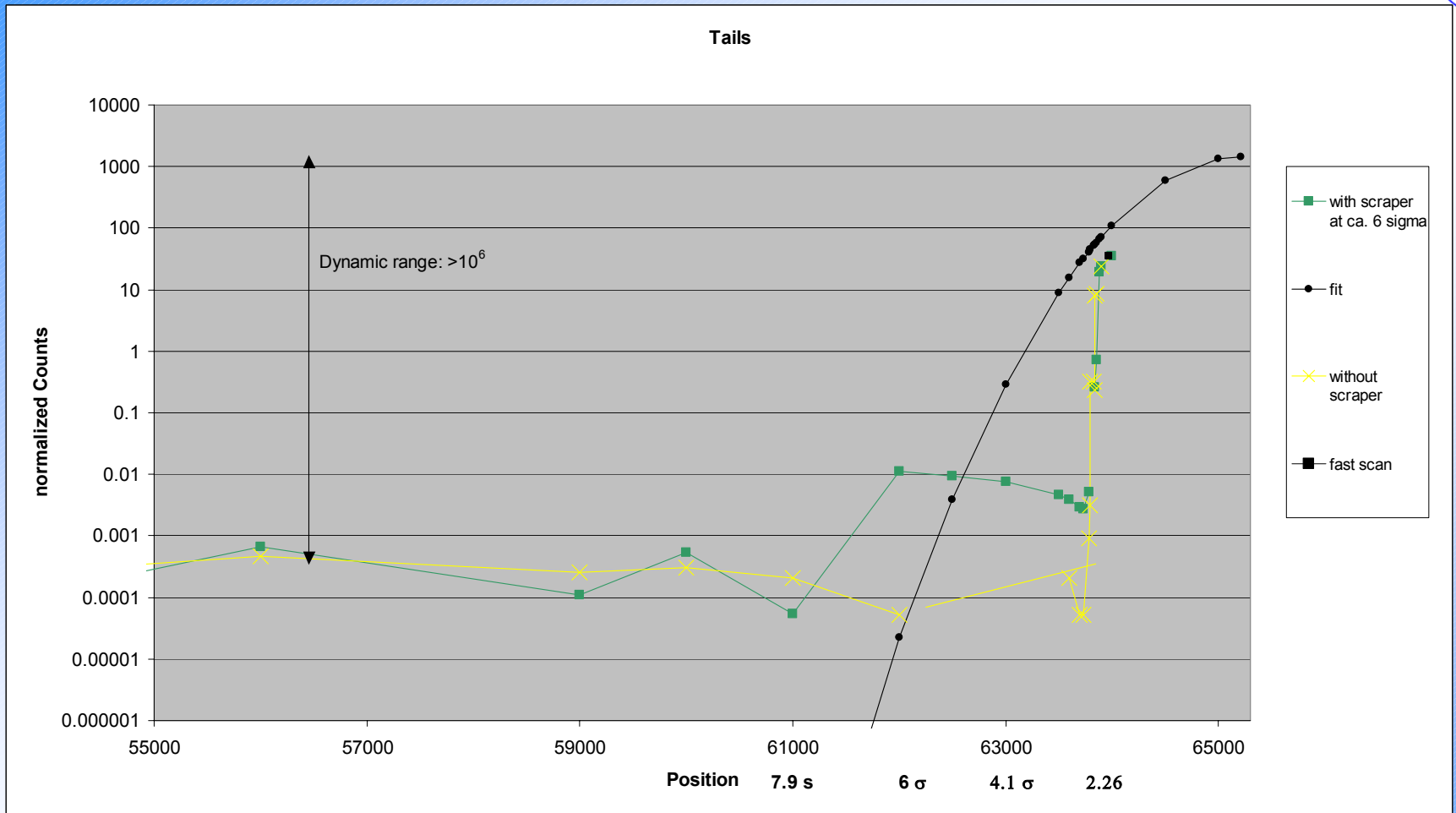The distribution of the signal from scintillation detector. E>1keV, **15 micron Quartz wire**

Efficiency: # Energy depositions/protons hitting wire:  $496/39087280 = 1.27 \cdot 10^{-5}$.
Varying threshold between  $10 - 200$ MeV => Efficiency $\approx 10^{-5}$ - $<10^{-7}$

Fast scan
E=920 GeV/c
P-e+ collisions

Normalized count rate: normalized to ADC value from fast scan
measured rate = normalized rate $* 1.8 * 10^4$

# Count rates during two tail scans

180 bunches, 45 mA, 2.8 * $10^{10}$ p/bunch

Signals due to beam losses

**out**   **6σ**   **≈2σ**

| Counting: with scraper | | without scraper | | 2 meas. Without scraper | | with scraper | |
|---|---|---|---|---|---|---|---|
| Position | Counts/9s | Position | Counts/9s | Position | Counts/9s | Position | Counts/9s |
| 0 | 22 | 0 | 21 | 0 | 474 | 0 | 437 |
| 39000 | 27 | 39000 | 20 | 39000 | 484 | 39000 | 431 |
| 45000 | 34 | 45000 | 19 | 45000 | 481 | 45000 | 440 |
| 50000 | 41 | 50000 | 24 | 50000 | 526 | 50000 | 437 |
| 53000 | 26 | 53000 | 20 | 53000 | 504 | | |
| 56000 | 37 | 56000 | 21 | 56000 | 452 | | |
| 59000 | 16 | 59000 | 19 | 59000 | 468 | | |
| 60000 | 35 | 60000 | 16 | 60000 | 490 | 60000 | 412 |
| 61000 | 26 | 61000 | 14 | 61000 | 525 | 61000 | 422 |
| 62000 | 231 | 62000 | 15 | 62000 | 972 | 62000 | 446 |
| 62500 | 198 | 63000 | 19 | | | 62500 | 724 |
| 63000 | 165 | 63400 | 18 | | | 62600 | 717 |
| 63500 | 110 | 63469 | 15 | | | 62680 | 810 |
| | | 63376 | 9 | | | 62800 | 966 |
| | | 63501 | 16 | | | 62873 | 1165 |
| | | 63545 | 19 | 62952 | 981 | 62990 | 1355 |
| 63600 | 95 | 63593 | 13 | | | 63090 | 1685 |
| 63700 | 79 | 63632 | 26 | 63182 | 1280 | 63180 | 2058 |
| 63730 | 75 | 63684 | 33 | 63283 | 1444 | 63280 | 2613 |
| 63780 | 118 | 63735 | 75 | 63377 | 1943 | 63390 | 3349 |
| 63840 | 4858 | 63792 | 6212 | 63491 | 3970 | 63490 | 4818 |
| 63853 | 13062 | 63797 | 4584 | 63565 | 9343 | 63580 | 7651 |
| 63885 | 349601 | 63832 | 155412 | 63689 | 150218 | 63670 | 23162 |
| 63900 | 443597 | 63835 | 164807 | 63784 | 3141843 | 63780 | 380240 |
| 63993 | 642042 | 63846 | 466030 | 63835 | 13839428 saturation! | 63846 | 2999750 |
| | | | | | | 63887 | 10138644 saturation! |

| Fast Scan: | ADC entry | | ADC entry | | | | ADC entry |
|---|---|---|---|---|---|---|---|
| 63970 | 35 | 63925 | 31 | 63820 | | | 8 |
| | | | | 63856 | | | 10 |
| | | | | 63892 | | | 14 |
| | | | | 63925 | | | 31 |

1. measurement          2. measurement with increased sensitivity

# Higher sensitivity by reduced threshold
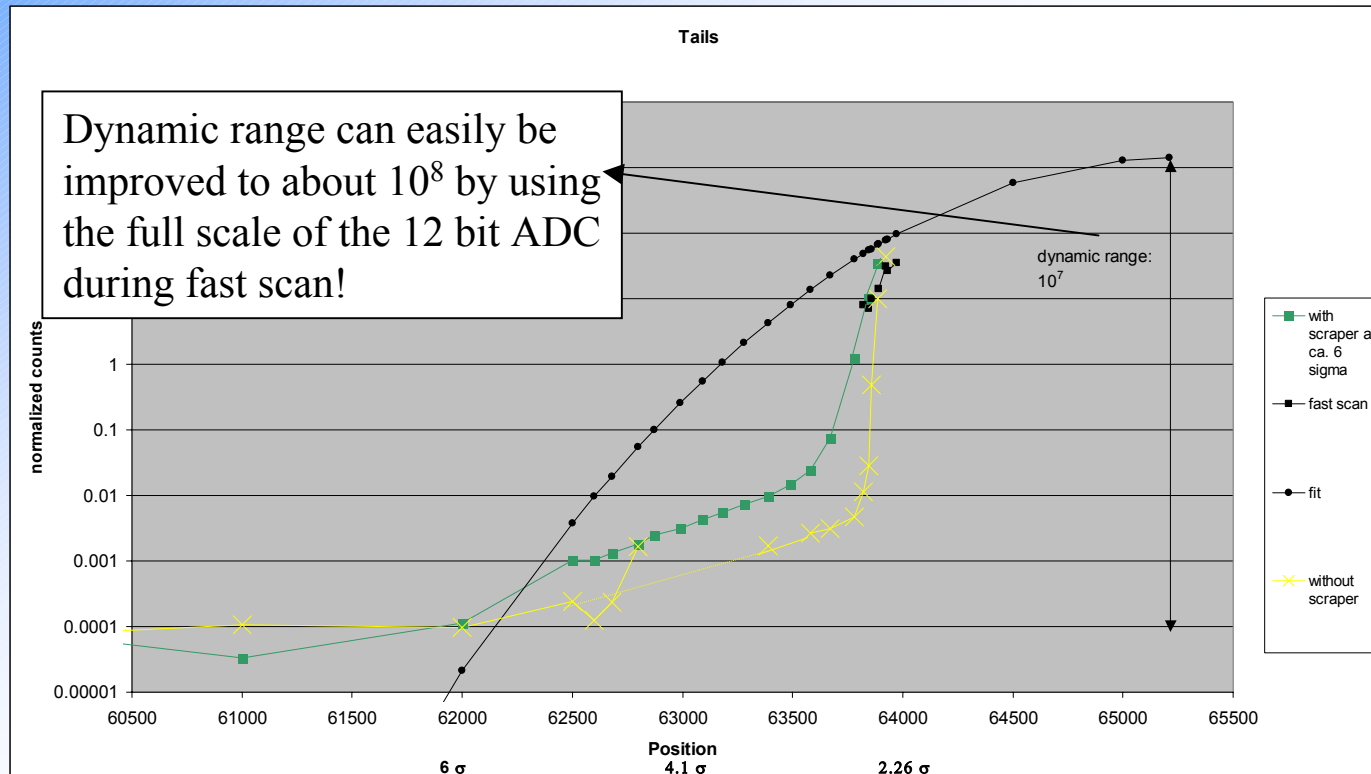


Normalized count rate: normalized to ADC value from fast scan
Real rate = normalized rate * $3*10^5$

Counting mode tail scans:

Improvements:
• Better overlap between fast scans and counting mode
    • fitting tails in fast scans
    • apply Poisson statistic at high count rates
    • reduced sensitivity? (burning the wire?)
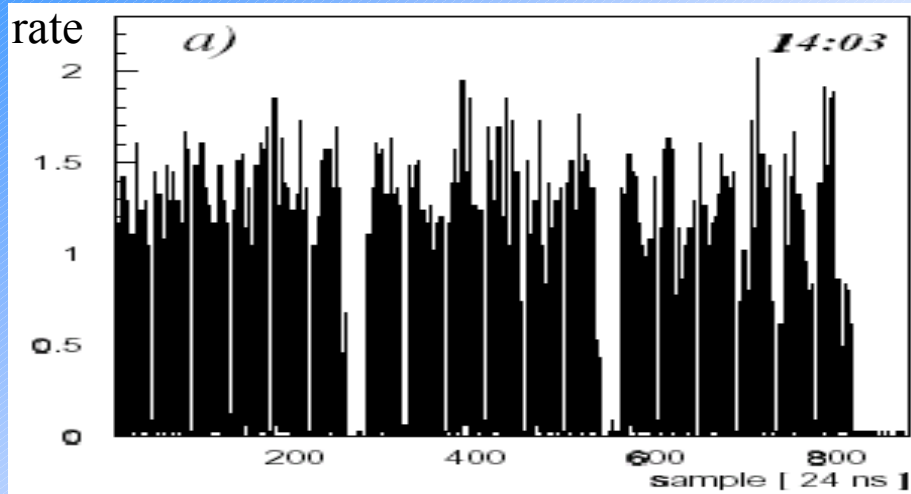• Noise (real beam loss) reduction ▷

Questions:

• What is the threshold?
  Calibration of sensitivity

• At which $\sigma$ the wire will burn?

• More parameters can be measured:

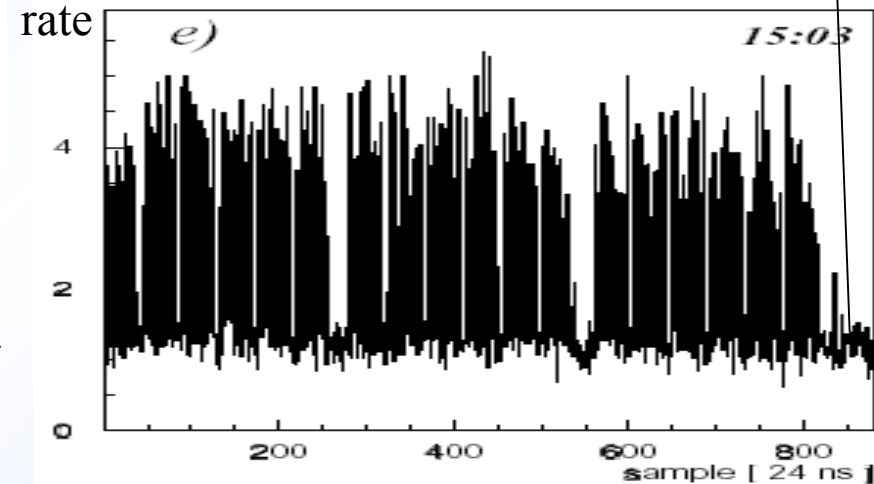Figure 1: Schematic view of the HERA–B wire target.
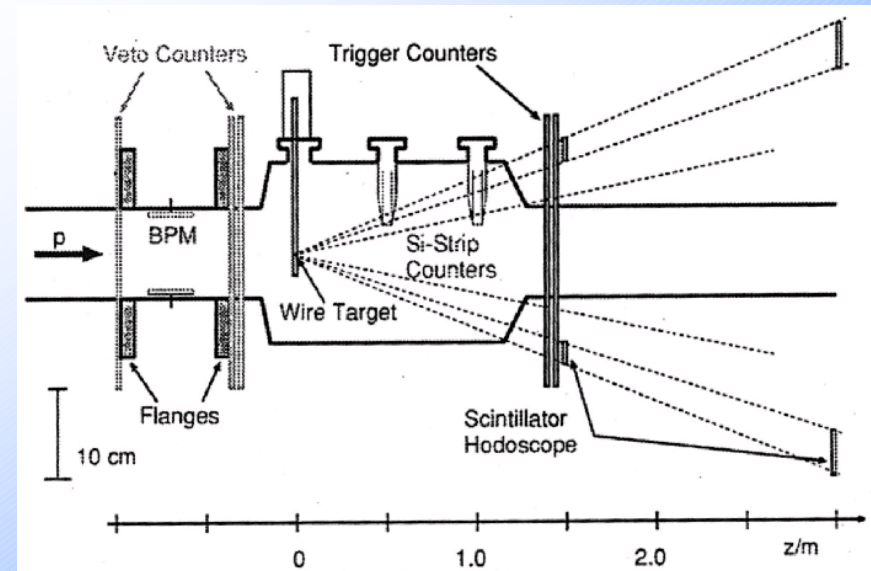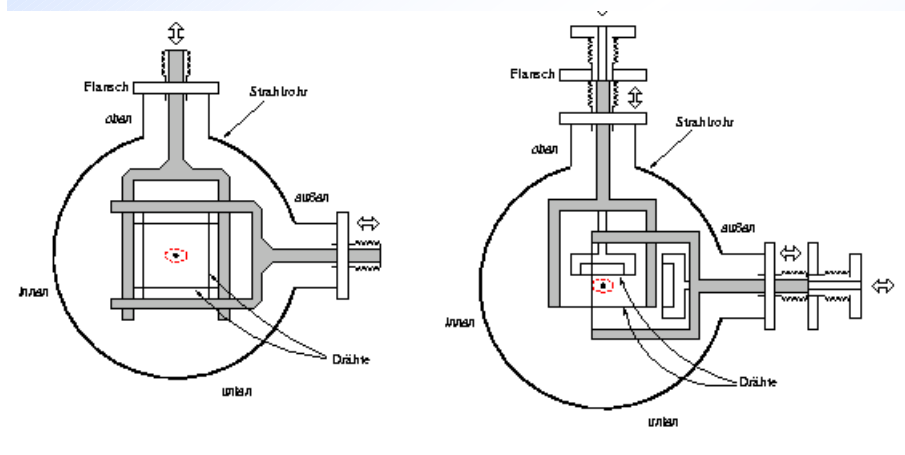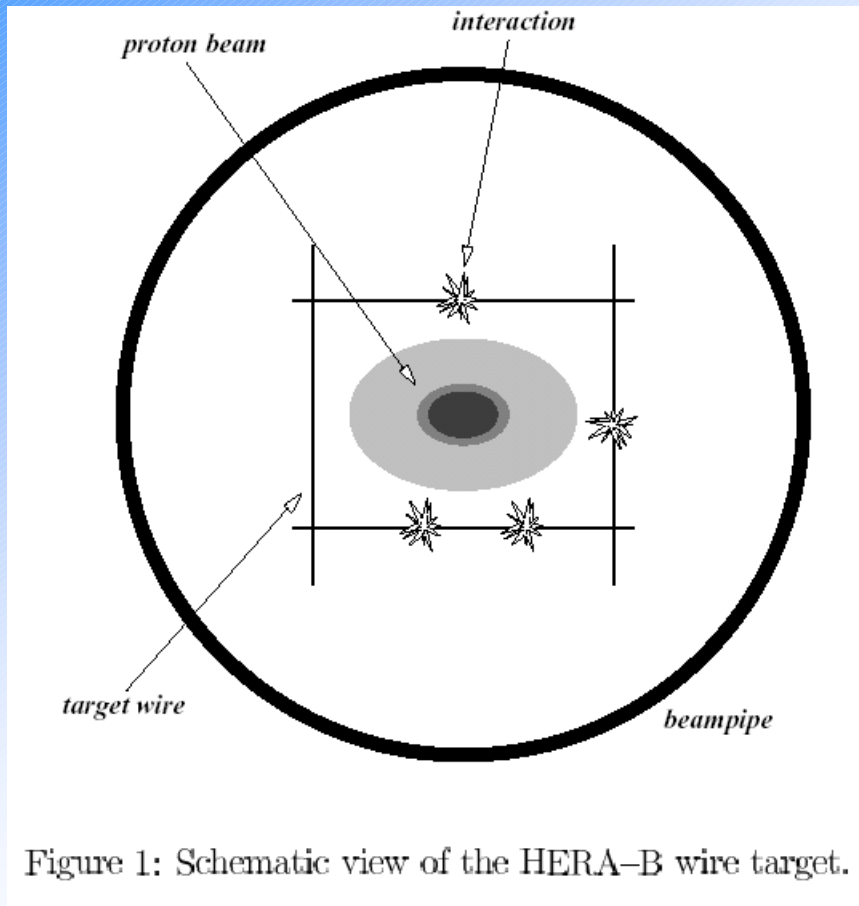
Detection efficiency > 50%

Detection of coasting beam

rate



a) 14:03

Note the increased rate in the
Bunch gaps (=coasting beam)
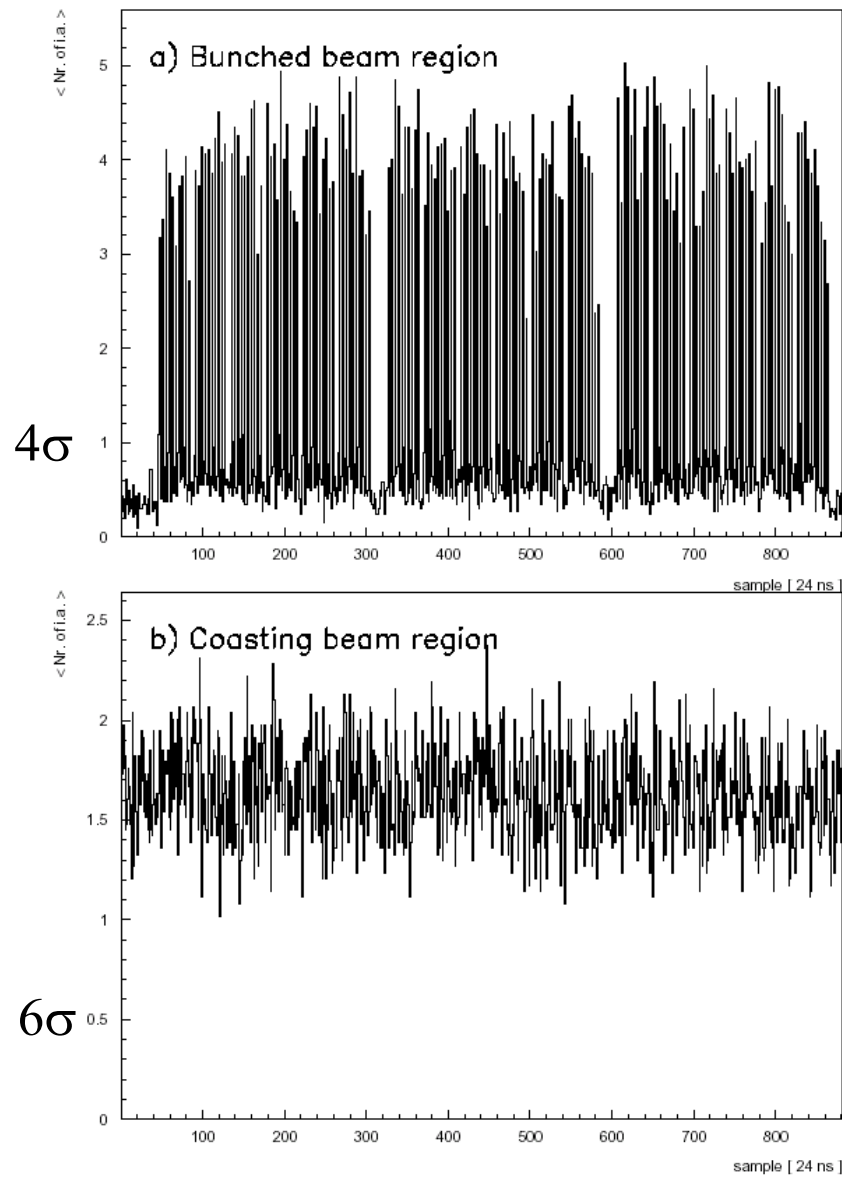
1 h

rate



e) 15:03

Another method:



Apr 28 01:39:43 1999
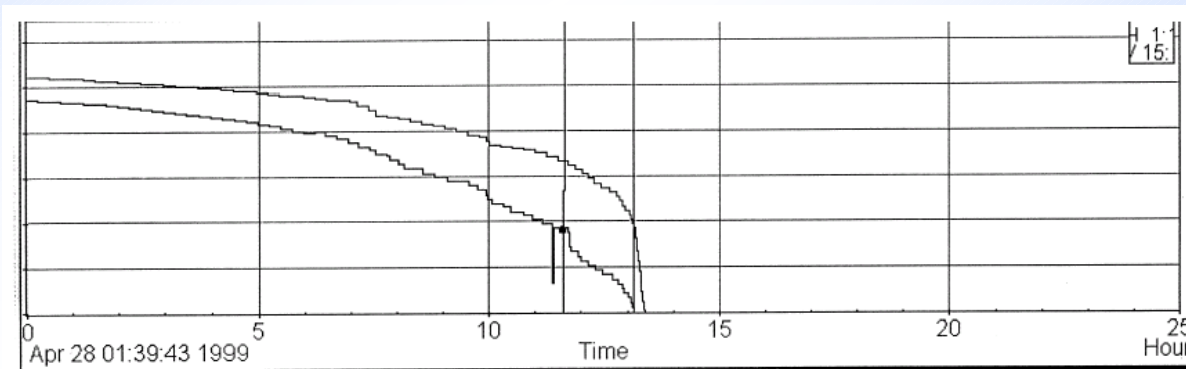
Total DC current (upper) and total bunch current (lower)

**Figure 11.2:** The time structure of the proton interaction for an outer target wire at different distances of the wire to the beam center: a) wire ≈ 4σ from the beam center and b) wire ≥ 6σ from the beam center.

The negative horizontal dispersion leads to signals on the outside wires

The HERA–B experiment [43] uses an internal wire target inserted into the halo of the stored HERA proton beam. While machine performance was improved during recent years, this halo practically vanished. Therefore the wire target has to be moved close to the beam core at about 3 to 4 $\sigma$ in order to keep the actual rate constant at the design rate of five interactions per bunch crossing. As it was observed, this leads to a high sensitivity of the interaction rate to beam orbit jitter of very small amplitudes. To overcome this situation, it has been suggested to artificially create some beam halo by means of tune modulation [42].
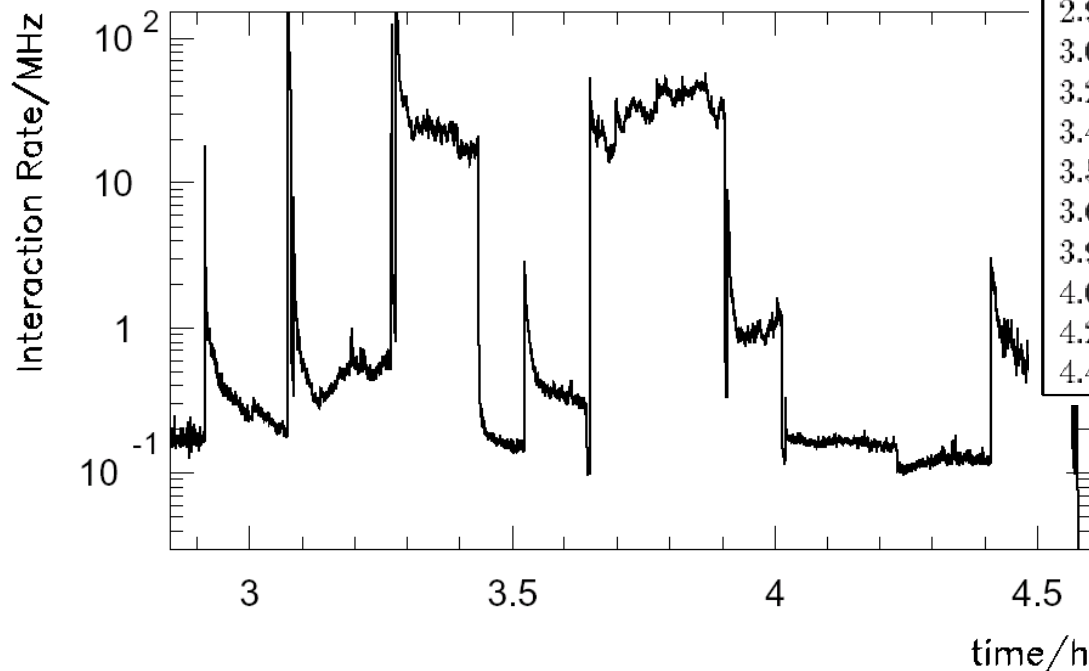
| time/h | $f_1$/Hz | $U_1$/V | $f_2$/Hz | $U_2$/V | rate/MHz |
|--------|----------|---------|----------|---------|----------|
| 2.8 | 0 | 0 | 0 | 0 | $0.18 \pm 0.03$ |
| 2.92 | 40 | 2.5 | 190 | 2.5 | $0.27 \pm 0.03$ |
| 3.08 | 20 | 2.5 | 190 | 2.5 | $0.35 \pm 0.04$ |
| 3.27 | 10 | 2.5 | 190 | 2.5 | $23 \pm 5$ |
| 3.4 | 0 | 0 | 0 | 0 | $0.16 \pm 0.02$ |
| 3.52 | 10 | 2.5 | 0 | 0 | $0.35 \pm 0.05$ |
| 3.65 | 10 | 2.5 | 190 | 2.5 | $30 \pm 0.8$ |
| 3.9 | 10 | 1.875 | 190 | 1.875 | $0.9 \pm 0.15$ |
| 4.02 | 10 | 1.25 | 190 | 1.25 | $0.17 \pm 0.02$ |
| 4.23 | 10 | 0.625 | 190 | 0.625 | $0.12 \pm 0.015$ |
| 4.42 | 10 | 2.5 | 0 | 0 | $0.6 \pm 0.1$ |



C. Montag's talk
Thu, afternoon

# Neighbor-buckets



Abbildung 5.3: *Das TDC–Spektrum beim Betrieb eines äußeren Drahttargets zeigt die zeitliche Zuordnung der Wechselwirkungen innerhalb eines Zeitraums von 202 ns bei einer zeitlichen Auflösung von 0,1 ns. Wechselwirkungen von Protonen zwischen den gefüllten Bunchen sind wie in Abbildung 5.2 beim Betrieb eines äußeren Targetdrahtes auch in den Daten des TDC–Systems zu sehen.*
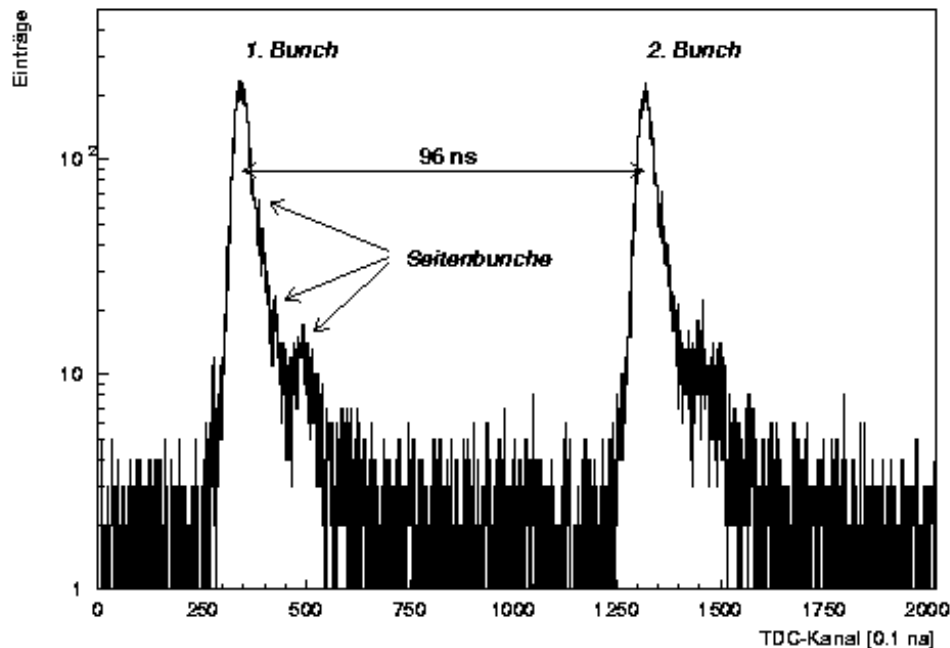


## Another method: Fast wall current monitor
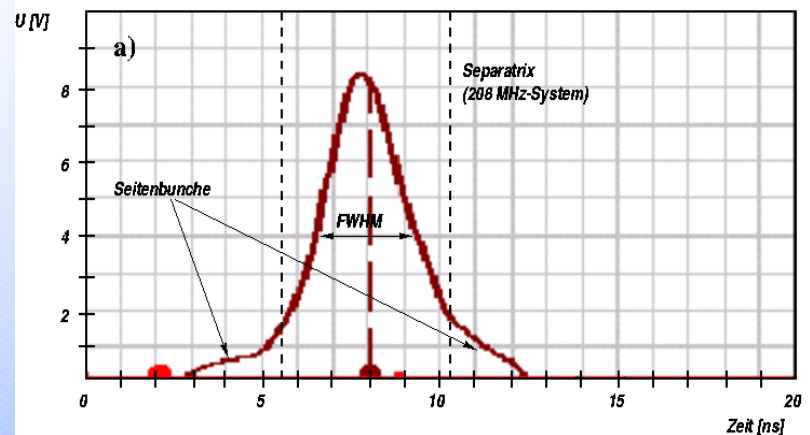
# 2) Temperature: Vibrating wire for beam tail scanning

S. G. Arutunian, N. M. Dobrovolski, M. R. Mailian, I. G. Sinenko, and I. E. Vasiniuk *Yerevan Physics Institute, Alikhanian Brothers Street 2, 375036, Yerevan, Armenia,*

For wire temperature measurement is proposed to use the strong dependence of frequency of normal oscillations of tensioned wire on temperature. Hence the stretched wire temperature can be obtained by measuring its natural oscillations frequency by an autogenerator electronic circuit with a positive feedback loop. The temperature sensitivity of the vibrating wire sensor estimated on the level $10^{-4}$ $^0$C. The wire vibration is achieved by an alternating current passing through the wire (about 1 mA) with a permanent magnetic at one end. The magnetic field can be concentrate only on definite parts of the wire, in a such way, that the remaining magnetic field free part of the wire can be used for scanning.
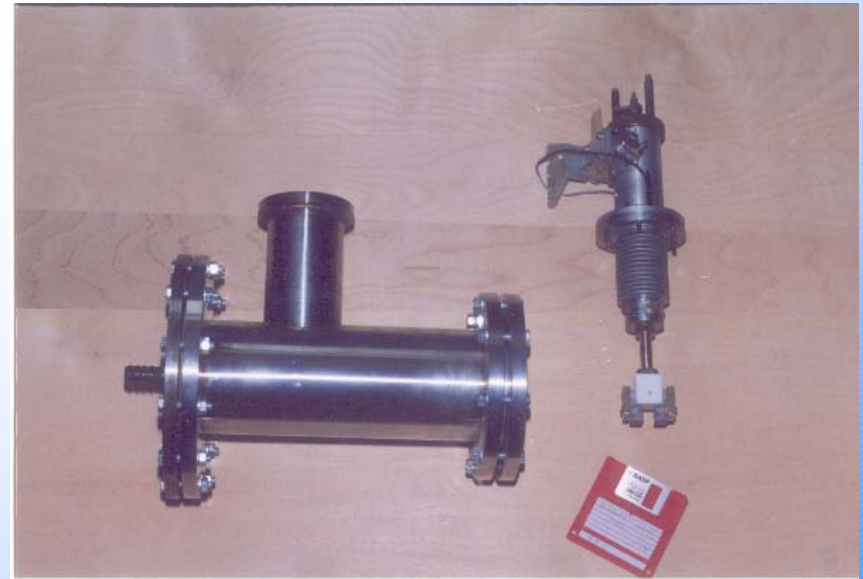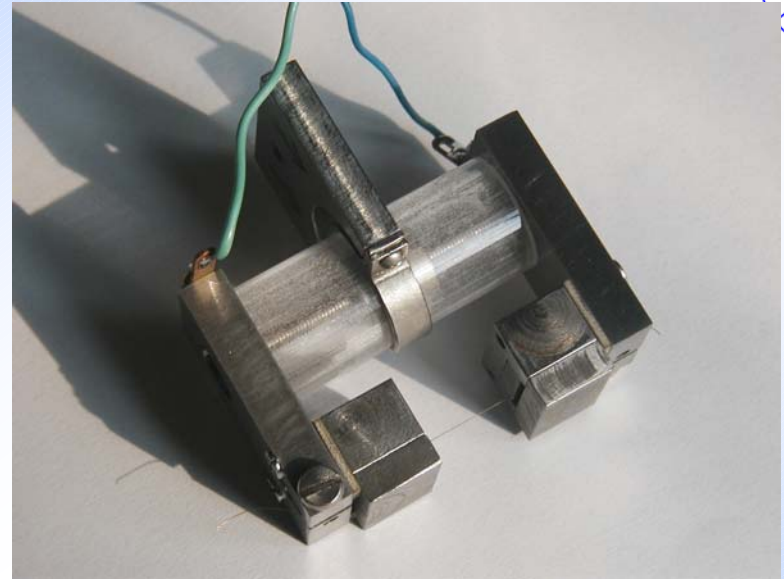




The part of vacuum chamber with the vibrating wire scanner and the translator mechanism.

# Vibrating wire scanner: first experimental results on the injector beam of Yerevan synchrotron

Arutunian S.G., Dobrovolski N.M., Mailian M.R., Vasiniuk I.E. Yerevan Physics Institute

The first experimental results of the transversal scanning of the injector electron beam (10 nA after collimation) of Yerevan synchrotron by scanner based on the vibrating wire (vibrating wire scanner - VWS) are presented and the corresponding horizontal beam profiles are obtained.
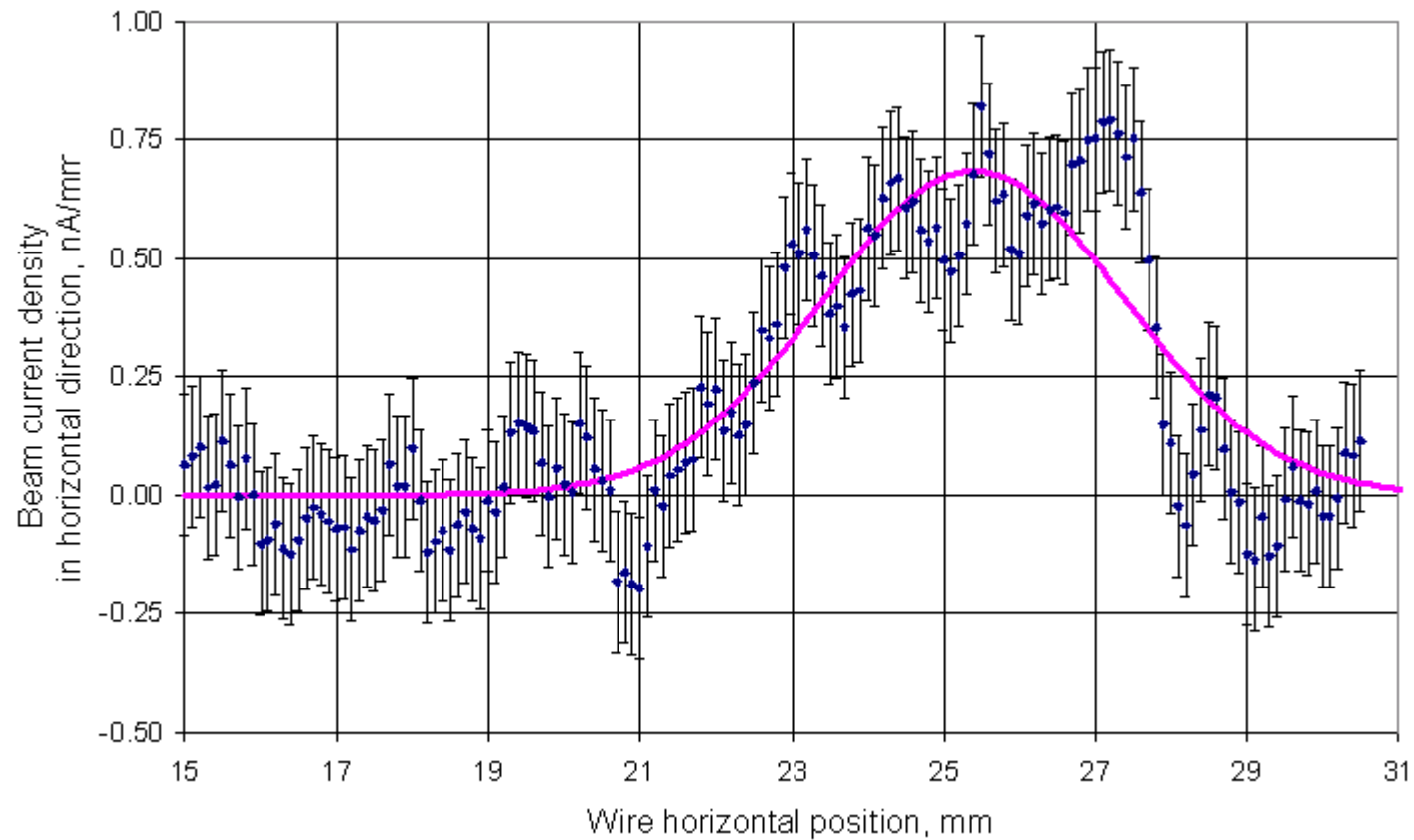
vibrating wire: 90 μm beryl-bronze wire

bunches with RF of 2797.3 MHz with pulse duration of 2 μs. The repetition rate of pulses was 50 Hz.

The figure presents the profile of the beam approximated by a normal distribution with σ = 1.48 mm and beam central position at 30.87 mm.
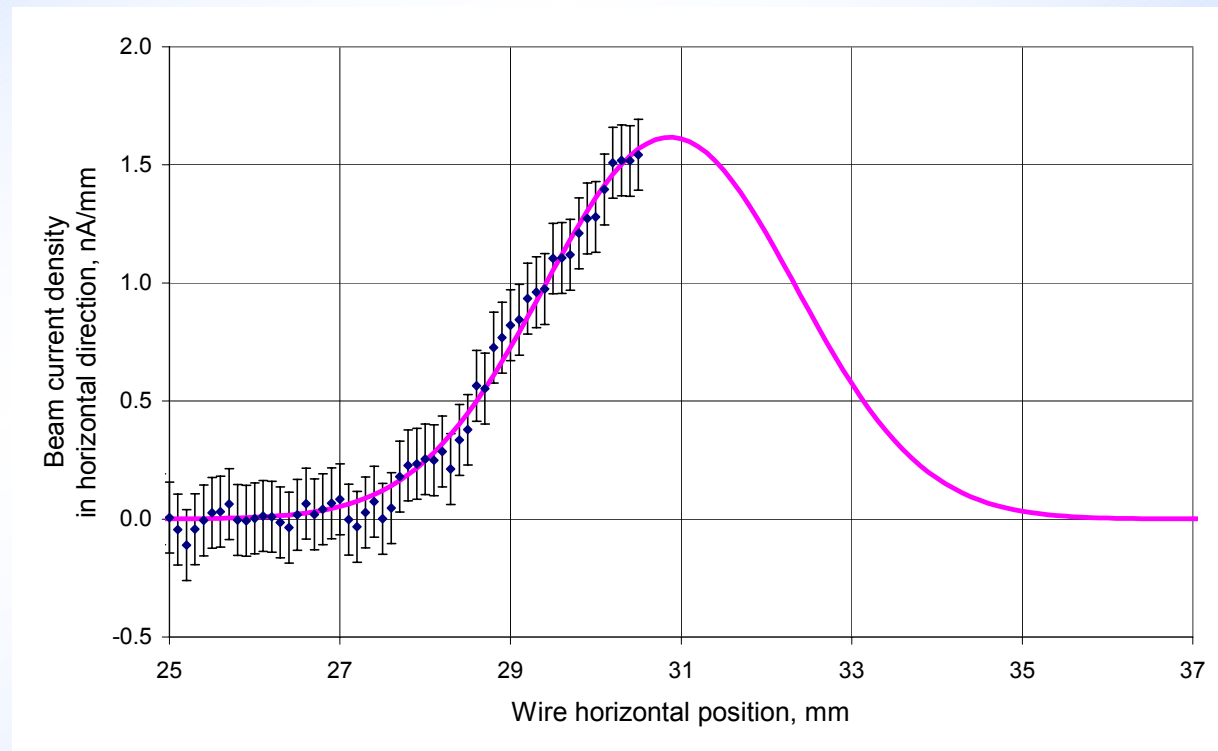


Because of short traveling distance only half of the beam was scanned.

Horizontal profile of the beam shifted towards the VWS (beam current 3.4 nA)

# *Calculations of "tail sensitivity"*

Let's estimate the sensitivity of VWS with respect to the lower limit of beam intensity. In this case radiation losses of wire temperature are negligible and the balance of temperature is determined by the thermal conduction along the wire. Let the temperature of the wire near its fixation points be $T_0$ and at the middle $T_0+T_m$ (triangular profile of the temperature along the wire). Thermo-conductive losses $P= 4\pi\lambda r_w^2 T_m/l$, where $\lambda$ is the thermo-conductivity of the wire with the radius $r_w$ and length l. Total power deposited on the wire $Q=(\pi/2)^{0.5}(r_w^2/\sigma_x)\exp(-x^2/2\sigma_x^2)(I_0 kdE/dy/e)$, where $\sigma_x$ is the beam size, x is the wire location with respect to the beam center, dE/dy are the ionization losses, k is coefficient transition ionization loss to heat of the wire. Usually k is approximately 0.3 . From the thermal balance follows that:

$T_m = (1/4(2\pi)^{0.5})(l/\sigma_x)\exp(-x^2/2\sigma_x^2) (I_0 kdE/dy/e)/\lambda$ . Note that there is no dependence of $T_m$ on the wire radius.
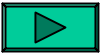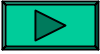
For beryllium-bronze wire and 100 mA proton beam with $\sigma_x$ = 0.6 cm (PETRA conditions) the value $T_m$ of about 0.01 K (vibrating wire thermal sensitivity at presence of electromagnetic noises) is achieved at **x = 5.7 σ.**

The following estimation agrees well with this calculation: At the Yerivan experiment a significant increase of the temperature was achieved at about 2 σ. At that wire position, the wire was hit by $1.8 \cdot 10^8$ e/s. For the 100 mA PETRA beam with a width of σ = 0.6 cm this amount is reached at about **6.1 σ**. Note that dE/dy for electrons and protons at ultra high energies is about identical.

Plans:

• VWS already installed in PETRA at DESY, waiting for beam.
• Both types of measurements can be done at the same time with the same scanner and with the fast scanner nearby.
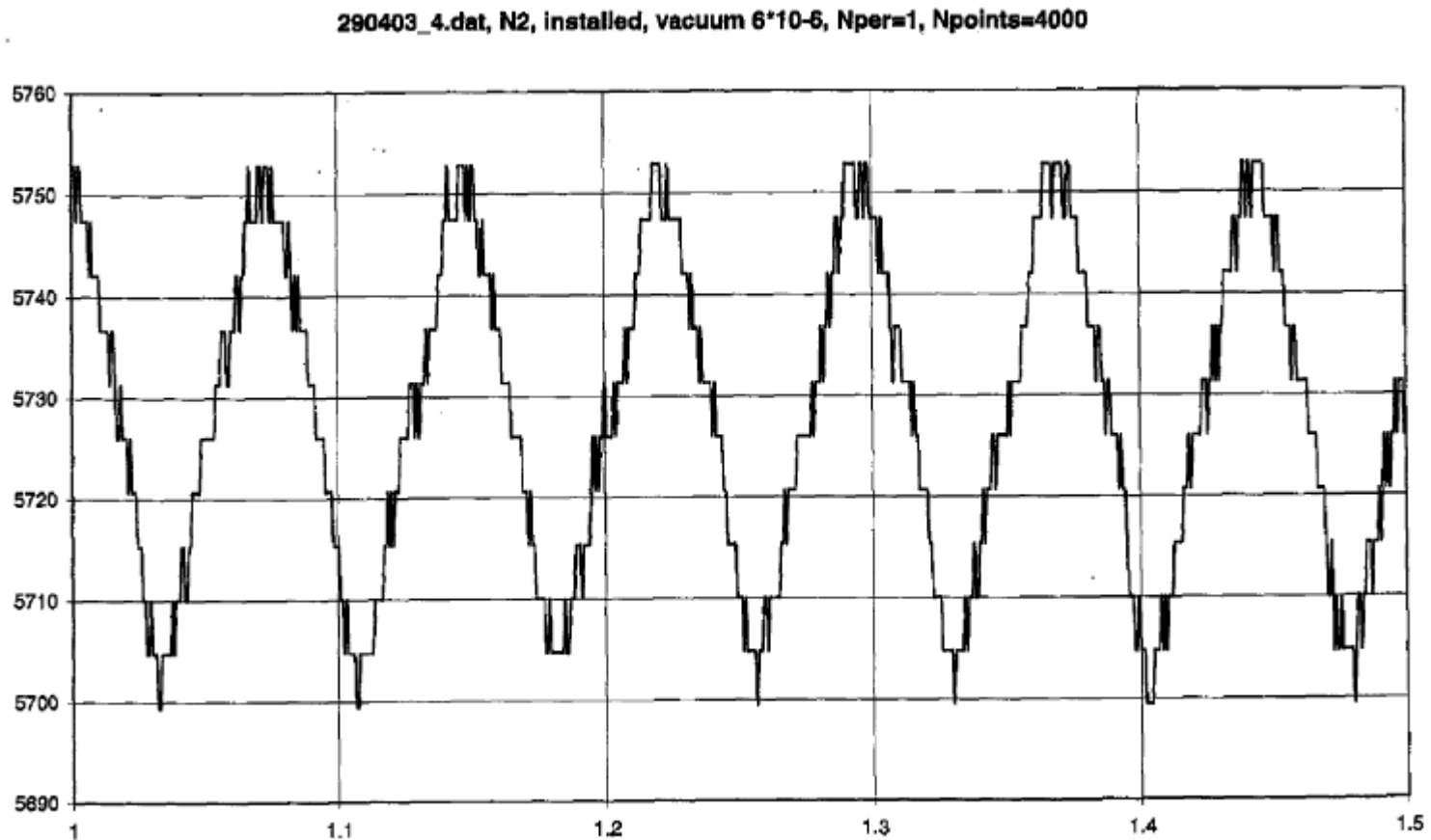
Questions:

• Noise in VWS ▶
• Overlap to fast scan (burning wire/other wire material)?
• DC beam vs. bunched beam ▶
• Heating of the wire by HOM? ▶

Summary:

**First measurements with both methods are very promising for beam tail measurements down to about 6 σ.**
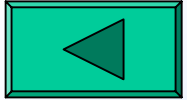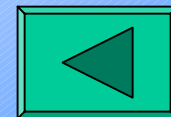
Mechanical vibrations due to water pumps, some 100 Hz.



290403_4.dat, N2, installed, vacuum 6*10-6, Nper=1, Npoints=4000

PETRA, p-beam, Comparision bunch structure model with mean current model
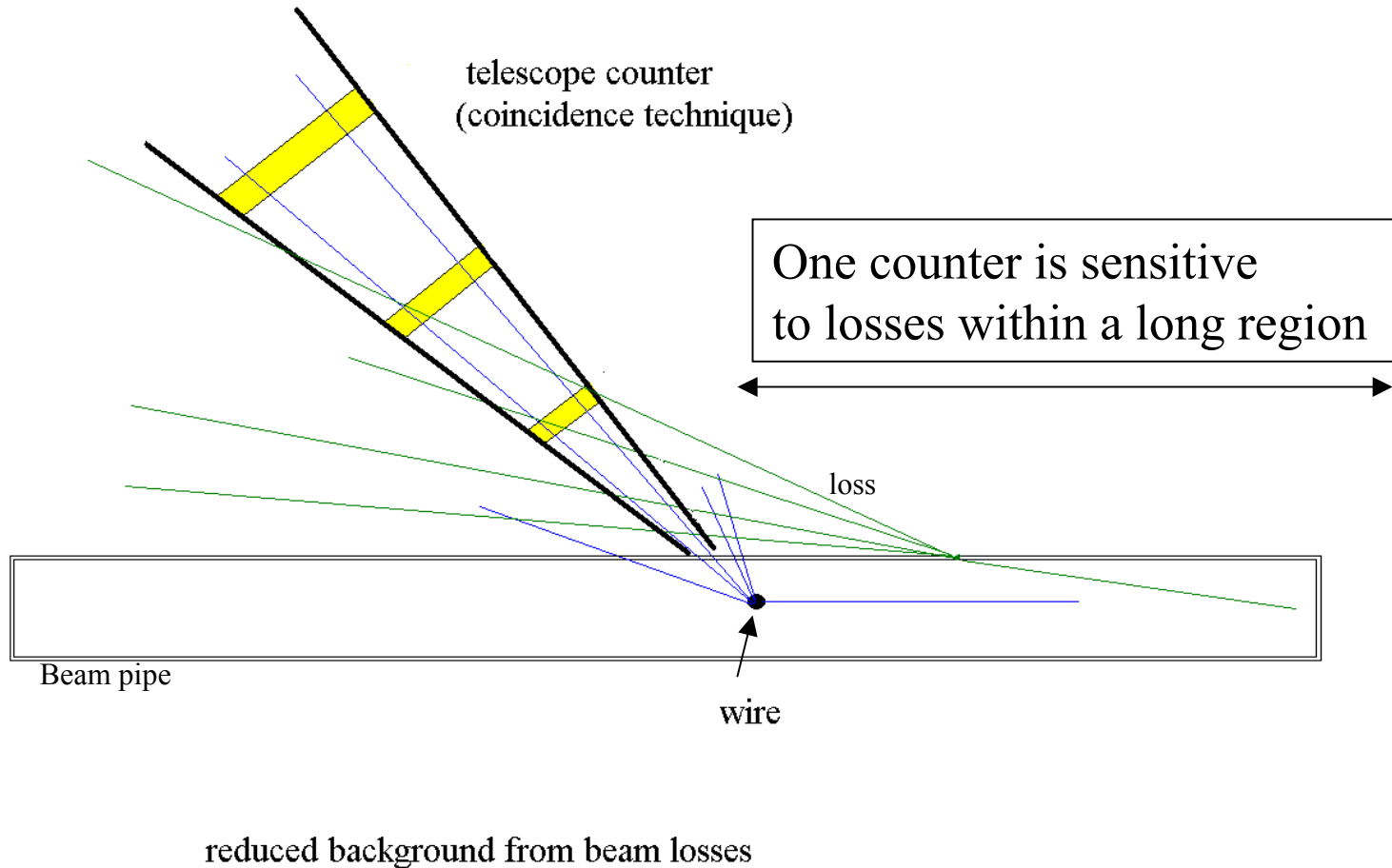Imean=100 mA, x=0 mm, tbunch=1 ns, tbunch-to-bunch=96 ns
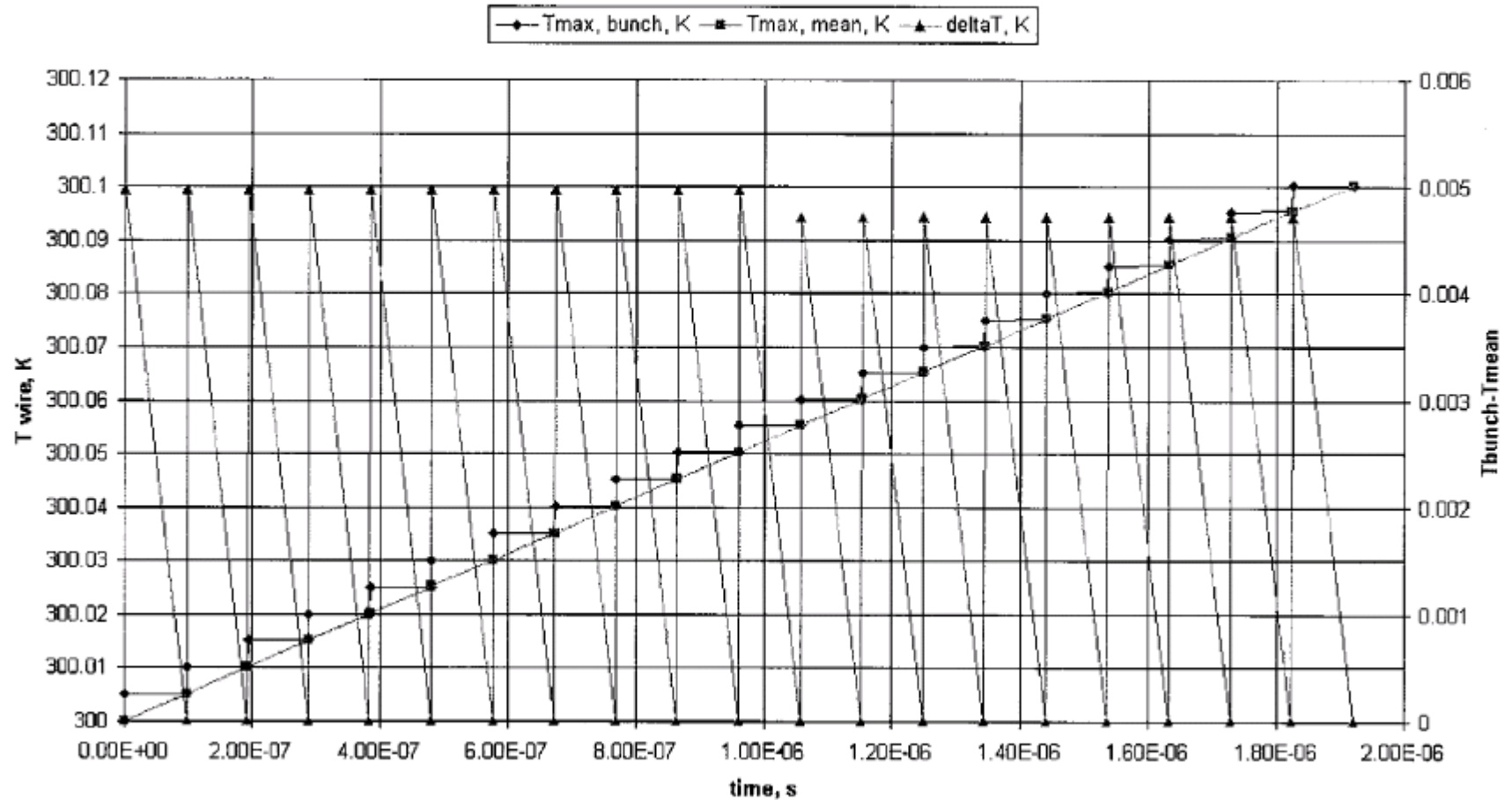
# For comparison: Secondary emission signal (efficiency = 3%)

45 mA beam, $\sigma$ = 5.27mm:

| Buch rate | | DC | 10.4 MHz | 10.4 kHz | 1 Hz |
|---|---|---|---|---|---|
| SEM current: | | [A] | e-/bunch | e-/bunch | e-/bunch |
| at 2 sigma | | 9.70E-07 | 6.02E+05 | 6.02E+08 | 6.02E+12 |
| at 5 sigma | | 2.67E-11 | 16.6 | 1.66E+04 | 1.66E+08 |
| at 6 sigma | | 1.09E-13 | 0.068 | 68 | 6.78E+05 |
| charge/10 ns: | | [A] | [A] | [A] | [A] |
| at 2 sigma | | 9.70E-07 | 0.000009632 | 0.009632 | 96.32 |
| at 5 sigma | | 2.67E-11 | 2.656E-10 | 2.656E-07 | 0.002656 |
| at 6 sigma | | 1.09E-13 | 1.088E-12 | 1.088E-09 | 0.000010848 |
| | | | | | |
| particles/bunch: | | DC | 2.80E+10 | 2.80E+13 | 2.80E+17 |

telescope counter
(coincidence technique)

One counter is sensitive
to losses within a long region

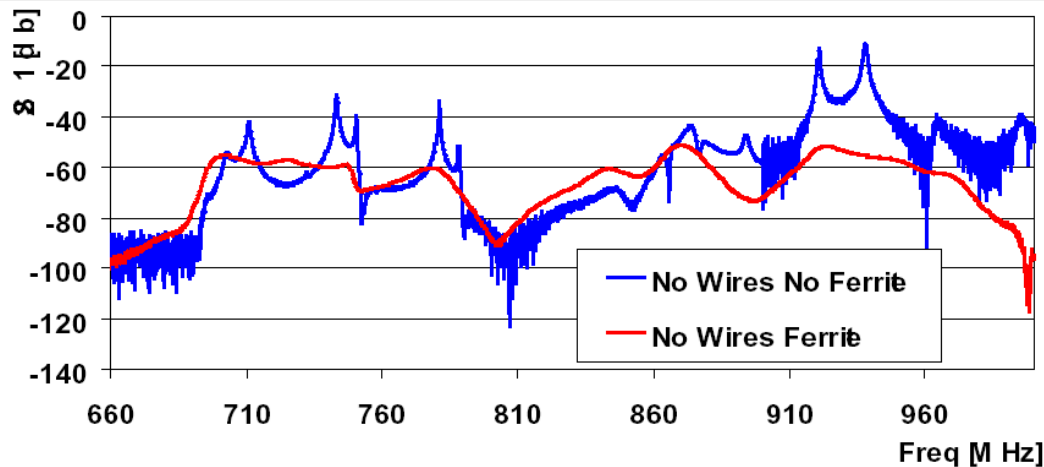loss

Beam pipe

wire

reduced background from beam losses

# SPS with LHC beam:

"The housing of the wire scanner acts as a cavity with a mode spectrum starting around 350MHz and high impedance values around 700 MHz. The carbon wire used so far appears to be an excellent RF absorber and thus dissipates a significant part of the beam-induced power.

……

As a cure to the wire heating due to the beam-wire coupling, the SPS wire scanner tanks have been equipped with ferrite tiles in order to damp the resonating modes."